CLAIMS

We claim:

1. A method for measuring impedance of a tissue, comprising:
charging a capacitor to a potential;
discharging the capacitor for a discharge period through the tissue;
measuring a voltage drop on the capacitor over the discharge period; and
determining the impedance of the tissue responsive to the potential, the voltage drop, and the discharge period.

2. A method according to claim 1, wherein charging the capacitor comprises:
providing a first circuit which is adapted to charge the capacitor to a first voltage;
providing a second circuit which is adapted to charge the capacitor to a second voltage;
measuring the potential on the capacitor;
determining a first charging period for the first circuit and a second charging period for the second circuit, responsive to the potential, so that the first and second charging periods substantially total to the predetermined period and so that the first and second voltages substantially total to the predetermined differential potential; and
operating the first circuit for the first charging period and the second circuit for the second charging period, the circuits being operated sequentially.

3. A method according to claim 2, wherein the first circuit comprises a resistive element through which the capacitor is charged by a substantially direct current (DC), and wherein the second circuit comprises an inductor, a switching element, and a diode, which are operative to generate a substantially alternating current (AC) and to rectify the AC so as to charge the capacitor.

4. A method for stimulating a tissue, comprising:
charging a capacitor to a first potential;
discharging the capacitor for a first discharge period through the tissue;
measuring a voltage drop on the capacitor over the first discharge period;
determining an impedance of the tissue responsive to the first potential, the voltage drop, and the first discharge period;
determining a second potential and a second discharge period, responsive to

the impedance and a predetermined desired tissue stimulation level;

charging the capacitor to the second potential; and

discharging the capacitor for the second discharge period through the tissue.

5. A method according to claim 4, wherein discharging the capacitor for the first discharge period and discharging the capacitor for the second discharge period each comprise discharging alternating pulses through the tissue, each alternating pulse comprising a positive-going pulse followed by a negative-going pulse, so that a time between the positive-going pulse and the negative-going pulse is substantially equal to half a period of the alternating pulses.

6. A method according to claim 4 or claim 5, wherein discharging the capacitor for the first discharge period and discharging the capacitor for the second discharge period each comprise discharging the capacitor responsive to a control signal generated by the tissue.

7. A method according to any of claims 4-6, wherein the second discharge period is subsequent to the first discharge period.

8. A method according to any of claims 4-7, wherein discharging the capacitor for the first discharge period and discharging the capacitor for the second discharge period each comprise discharging biphasic pulses through the tissue, each biphasic pulse comprising a positive-going pulse followed by a negative-going pulse, so that a time between the positive-going pulse and the negative-going pulse is substantially less than half a period of the biphasic pulses.

9. A method according to claim 8, wherein discharging the biphasic pulses comprises discharging a first biphasic pulse comprising a first positive-going pulse followed by a first negative-going pulse, followed by a second biphasic pulse comprising a second negative-going pulse followed by a second positive-going pulse.

10. Apparatus for measuring impedance of a tissue, comprising:

a capacitor; and

circuitry which is adapted to:

charge the capacitor to a potential,

discharge the capacitor for a discharge period through the tissue,

measure a voltage drop on the capacitor over the discharge period, and

determine the impedance of the tissue responsive to the potential, the voltage

drop, and the discharge period.

11. Apparatus according to claim 10, wherein the circuitry comprises:

a first circuit which is adapted to charge the capacitor to a first voltage;

a second circuit which is adapted to charge the capacitor to a second voltage;

and wherein the circuitry is further adapted to measure the potential on the capacitor,

determine a first charging period for the first circuit and a second charging period for the second circuit, responsive to the potential, so that the first and second charging periods substantially total to the predetermined period and so that the first and second voltages substantially total to the predetermined differential potential, and

operate the first circuit for the first charging period and the second circuit for the second charging period, the circuits being operated sequentially.

12. Apparatus according to claim 11, wherein the first circuit comprises a resistive element through which the capacitor is charged by a substantially direct current (DC), and wherein the second circuit comprises an inductor, a switching element, and a diode, which are operative to generate a substantially alternating current (AC) and to rectify the AC so as to charge the capacitor.

13. Apparatus for changing a potential across a capacitor by a predetermined differential potential in a predetermined time period, comprising:

a first circuit which is adapted to charge the capacitor to a first voltage;

a second circuit which is adapted to charge the capacitor to a second voltage; and

a controller which measures the potential on the capacitor, and responsive thereto and to the predetermined differential potential and the predetermined time period operates the first circuit and the second circuit sequentially for respective periods of time substantially totaling the predetermined time period so as to charge the capacitor by the predetermined differential potential substantially totaling the first and the second voltages.

14. Apparatus according to claim 13, and comprising a memory wherein is stored a first charging rate for the first circuit and a second charging rate for the second circuit, and wherein the controller is adapted to determine the respective periods of time responsive to the first and the second charging rates.

15. Apparatus according to claim 13 or 14, and comprising a battery supplying a battery voltage, wherein the first circuit comprises a resistive element through which the capacitor is charged by a substantially direct current (DC), and wherein the second circuit comprises an inductor, a switching element, and a diode, which are operative to generate a substantially alternating current (AC) and to rectify the AC so as to charge the capacitor, wherein the first voltage is a predetermined fraction, greater than 0 and less than 1, of the battery voltage, and wherein the predetermined differential potential is greater than the battery voltage.

16. Apparatus according to any of claims 13-15, wherein the first circuit dissipates a first energy to charge the capacitor to the first voltage and the second circuit dissipates a second energy to charge the capacitor to the second voltage, and wherein the controller is adapted to determine the respective periods of time responsive to the first and the second energies.

17. Apparatus according to claim 16, wherein the controller is adapted to determine the respective periods so that a sum of the first and the second energies is a minimum.

18. Apparatus according to claim 17, wherein the first circuit comprises a resistive element through which the capacitor is charged by a substantially direct current (DC), and wherein the second circuit comprises an inductor, a switching element, and a diode, which are operative to generate a substantially alternating current (AC) and to rectify the AC so as to charge the capacitor.

19. Apparatus for stimulating a tissue having a tissue capacitance, comprising:

a capacitor;

circuitry which is adapted to:

charge the capacitor to a potential,

discharge the capacitor for a discharge period through the tissue; and

a resistive element, having a resistance which is controlled by the circuitry, and which is coupled to the circuitry and which is adapted to substantially short-circuit the tissue capacitance responsive to a control signal generated by the circuitry.

20. Apparatus according to claim 19, wherein the resistance comprises a value so that substantially no anodal break excitation occurs in the tissue.

21. Apparatus according to claim 19 or claim 20, wherein the circuitry is adapted

to generate the control signal at a time so as to implement a predetermined stimulation level to the tissue.

22. Apparatus according to claim 21, wherein the time directly follows a completion of the discharge period.

23. Apparatus for measuring a voltage, comprising:

a battery which supplies a direct current (DC) voltage;

a DC voltage reference source, which generates a substantially invariant reference voltage, and which is powered by the battery;

an analog-to-digital converter (ADC) which generates a digital value responsive to receiving the reference voltage as an analog input, and which is powered by the battery;

a memory, comprising an ADC look-up table having a one-to-one mapping between the digital value and the DC voltage; and

a processor, which is adapted to use the ADC look-up table to determine the DC voltage responsive to the digital value.

24. Apparatus according to claim 23, wherein the ADC look-up table comprises a further one-to-one mapping between the digital value and a multiplicative correction factor which is operative to multiply the digital value so as to generate an improved digital value, and wherein the ADC is adapted to receive an alternative DC voltage and to generate an alternative digital value responsive thereto, and wherein the processor is adapted to determine the alternative DC voltage responsive to the alternative digital value and the multiplicative correction factor.

25. Apparatus according to claim 24, and comprising a plurality of resistors acting as a voltage divider which generate the alternative DC voltage, and wherein one of the resistors comprises an internal resistance of the ADC.

26. A method for changing a potential across a capacitor by a predetermined differential potential in a predetermined time period, comprising:

providing a first circuit which is adapted to charge the capacitor to a first voltage;

providing a second circuit which is adapted to charge the capacitor to a second voltage;

measuring a potential on the capacitor;

determining a first charging period for the first circuit and a second charging period for the second circuit, responsive to the potential, so that the first and second charging periods substantially total to the predetermined period and so that the first and second voltages substantially total to the predetermined differential potential; and

operating the first circuit for the first charging period and the second circuit for the second charging period, the circuits being operated sequentially.

27. A method according to claim 26, and comprising storing a first charging rate for the first circuit and a second charging rate for the second circuit in a memory, and wherein determining the first charging period and the second charging period comprises determining the charging periods responsive to the first and the second charging rates.

28. A method according to claim 26 or claim 27, and comprising providing a battery that supplies a battery voltage, wherein the first circuit comprises a resistive element through which the capacitor is charged by a substantially direct current (DC), and wherein the second circuit comprises an inductor, a switching element, and a diode, which are operative to generate a substantially alternating current (AC) and to rectify the AC so as to charge the capacitor, wherein the first voltage is a predetermined fraction, greater than 0 and less than 1, of the battery voltage, and wherein the predetermined differential potential is greater than the battery voltage.

29. A method according to any of claims 26-28, wherein the first circuit dissipates a first energy to charge the capacitor to the first voltage and the second circuit dissipates a second energy to charge the capacitor to the second voltage, and wherein determining the first charging period and the second charging period comprises determining the charging periods responsive to the first and the second energies.

30. A method according to claim 29, wherein determining the charging periods comprises determining the charging periods so that a sum of the first and the second energies is a minimum.

31. A method according to claim 30, wherein the first circuit comprises a resistive element through which the capacitor is charged by a substantially direct current (DC), and wherein the second circuit comprises an inductor, a switching element, and a diode, which are operative to generate a substantially alternating current (AC) and to rectify the AC so as to charge the capacitor.

32. Apparatus for stimulating tissue having a capacitance, comprising:

charge circuitry which is adapted to apply a potential to the tissue, causing a voltage to develop across the capacitance of the tissue; and

discharge circuitry which is adapted to inject a current to the tissue so as to discharge the capacitance, the current being substantially independent of the voltage across the capacitance.

33. Apparatus according to claim 32, wherein the charge circuitry comprises a stimulation capacitor, an inductor, and a micro-controller which is adapted to apply pulses having a variable duty cycle to the inductor, and wherein the micro-controller causes the inductor to charge the stimulation capacitor to the voltage by altering the variable duty cycle.

34. Apparatus according to claim 32 or claim 33, wherein the current is substantially fixed.

35. Apparatus according to any of claims 32-34, wherein the potential causes a stimulation current in the tissue, and wherein the current injected by the discharge circuitry is a substantially pre-set fraction of the stimulation current.

36. Apparatus according to any of claims 32-35, wherein the discharge circuitry is adapted to measure the voltage across the capacitance, and is adapted to halt injection of the current to the tissue when the voltage is substantially zero.

37. Apparatus according to any of claims 32-36, and comprising a micro-controller which is adapted to measure a time to discharge the capacitance, and to generate a measure of the capacitance in response to the time.

38. Apparatus according to any of claims 32-37, and comprising a micro-controller which is adapted to measure a time to apply the potential to the tissue, and to generate a measure of the capacitance in response to the time.

39. Apparatus according to any of claims 32-38, wherein the charge circuitry is adapted to measure an impedance of the tissue, and to alter the potential applied to the tissue in response to the impedance.

40. Apparatus according to any of claims 32-39, wherein the current comprises a value that substantially eliminates anodal break excitation of the tissue.

41. Apparatus according to claim 40, wherein the value is less than a pre-set

fraction of a stimulation current caused by the potential.

42. Apparatus according to claim 41, wherein the pre-set fraction is approximately 5%.

43. Apparatus according to claim 32, and comprising:

a battery having a first battery terminal and a second battery terminal coupled to ground and generating a battery voltage which powers at least a first part of the charge circuitry and at least a second part of the discharge circuitry; and

a first and a second stimulation electrode between which the capacitance is formed,

wherein the first battery terminal and the first stimulation electrode are connected, and wherein the charge circuitry generates the potential between the first and the second stimulation electrodes, and wherein the discharge circuitry injects the current between the first and the second stimulation electrodes.

44. Apparatus according to claim 43, and comprising:

a stimulation capacitor which receives a stimulation potential generated by the charge circuitry; and

a detector which monitors a second-stimulation-electrode potential on the second stimulation electrode, the detector being coupled between ground and the stimulation potential.

45. Apparatus according to claim 44, and comprising a micro-controller which receives a Boolean signal from the detector in response to the second-stimulation-electrode potential, and which decrements a targeted voltage set by the micro-controller in response to the signal being true, and which increments the targeted voltage in response to the signal being false.

46. Apparatus according to claim 32, and comprising:

a detector which monitors a state of at least part of the charge circuitry, and which generates a state signal in response to the state; and

a micro-controller which receives the state signal and which sets the potential in response thereto.

47. Apparatus according to claim 46, wherein the micro-controller generates a pulse, at the potential, in a sequence of pulses and sets a target voltage in response to the state signal and the potential, and wherein the charge circuitry is adapted to alter

the potential to a future potential in response to the target voltage, and to apply the future potential to a subsequent pulse in the sequence.

48. A method for stimulating tissue having a capacitance, comprising:

applying a potential to the tissue so as to cause a voltage to develop across the capacitance of the tissue; and

injecting a current to the tissue so as to discharge the capacitance, the current being substantially independent of the voltage across the capacitance.

49. A method according to claim 48, wherein the current is substantially fixed.

50. A method according to claim 48 or claim 49, wherein the potential causes a stimulation current in the tissue, and wherein the current injected is a substantially pre-set fraction of the stimulation current.

51. A method according to any of claims 48-50, and comprising measuring the voltage across the capacitance, and halting injection of the current to the tissue when the voltage is substantially zero.

52. A method according to any of claims 48-51, and comprising measuring a time to discharge the capacitance, and generating a measure of the capacitance in response to the time.

53. A method according to any of claims 48-52, and comprising measuring a time to apply the potential to the tissue, and generating a measure of the capacitance in response to the time.

54. A method according to any of claims 48-53, and comprising measuring an impedance of the tissue, and altering the potential applied to the tissue in response to the impedance.

55. A method according to any of claims 48-54, wherein the current comprises a value that substantially eliminates anodal break excitation of the tissue.

56. A method according to claim 55, wherein the value is less than a pre-set fraction of a stimulation current caused by the potential.

57. A method according to claim 56, wherein the pre-set fraction is approximately 5%.

58. A method according to claim 48, and comprising:

providing a battery having a first battery terminal and a second battery terminal coupled to ground;

providing a first and a second stimulation electrode between which the capacitance is formed;

connecting the first battery terminal and the first stimulation electrode;

generating the potential between the first and the second stimulation electrodes;

injecting the current between the first and the second stimulation electrodes;

providing a stimulation capacitor which receives a stimulation potential in response to applying the potential;

coupling a detector between ground and the stimulation potential; and

monitoring with the detector a second-stimulation-electrode potential on the second stimulation electrode.

59. A method according to claim 58, and comprising:

receiving a Boolean signal from the detector in response to the second-stimulation-electrode potential;

setting a targeted voltage;

decrementing the targeted voltage in response to the signal being true; and

incrementing the targeted voltage in response to the signal being false.

60. A method according to claim 48, and comprising:

monitoring a state of charge circuitry adapted to apply the potential, and generating a state signal in response to the state; and

receiving the state signal and setting the potential in response thereto.

61. A method according to claim 60, and comprising:

generating a pulse, at the potential, in a sequence of pulses and setting a target voltage in response to the state signal and the potential;

altering the potential to a future potential in response to the target voltage; and

applying the future potential to a subsequent pulse in the sequence.

62. Apparatus for stimulating tissue having a capacitance, comprising:

charge circuitry which is adapted to apply a potential to the tissue, causing a voltage to develop across the capacitance of the tissue;

discharge circuitry which is adapted to inject a current to the tissue so as to

discharge the capacitance; and

feedback circuitry which is adapted to monitor the potential and to control the current in response to the potential.

63. A method for stimulating tissue having a capacitance, comprising:

applying a potential to the tissue so as to cause a voltage to develop across the capacitance of the tissue;

injecting a current to the tissue so as to discharge the capacitance;

monitoring the potential to generate a monitored potential; and

controlling the current in response to the monitored potential.